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Teaching as a Design Process: A Framework for Design-based Research in Engineering Education

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Motivation & Background

Framing teaching as a design process, Laurillard explains how teaching is more like engineering than science[1]. She uses this metaphor to explain that it is less like hypothesis testing and manipulation of controlled conditions than it is like working to design solutions for problems within the constraints and affordances of human environments. Additional authors have characterized engineering as "design under constraints." (p. 7) [2,3] She selected this metaphor for teaching to provoke a discussion in the space of instructional technology, but it is appropriate to a discussion of teaching even without technology. Expanding on this sense of teaching as a design process with constraints, we can consider design-based research as a framework for organizing research studies in engineering education. There have been relatively few studies in engineering education that characterize themselves as design research studies, but it is an expanding framework within the education research community broadly[4,5]. This paper uses one small-scale, design-based research study of faculty development to explain the principles and practices that can make up a design-based research study of teaching and learning. Design plays a role at two levels in the process. At the first level, instructors are designing new teaching strategies. At the second level, the researchers are designing a model for teaching development for faculty. In addition, how does conceptualizing teaching as a design process inform a teaching development model for instructors?

Literature Review

We build in this project on other frameworks for research in education that examine how educational products (e.g., curriculum) or processes are designed for the classroom. In many of these cases, there are models, resources or tools being designed to support teaching and learning. For example, in research about the design of curriculum, Clements describes multiple stages in the life of the materials from the ideal curriculum to the planned curriculum to the implemented curriculum and the learned curriculum[6]. Each of these phases is a part of the research and design process for curriculum as it is created and used in classrooms. In a similar vein, Kelly examines the use of design-based research in education by describing an example of research-based software development in mathematics education and points to ways engineering education research could adopt design research methodologies[5] for iteratively creating and testing innovative teaching methods.

Design has been used in engineering education primarily from the point of view of developing students' abilities as designers and considering their use of design processes in learning to be engineers [7] or from the perspective of design professionals[8]. We use "design research" in this context to mean not the study of design professionals or investigating students' design process, but rather as a theoretical and methodological framework for education research[4,5,9–12]. Defined broadly, design research is a framework to examine the design and development of innovations or models focusing both on understanding the process of decision-making that results in the design and the impact of the design. Early examples of design research in the 1990s (more often called design experiments[13,14] at that time) consider how to conduct research with children in the classroom instead of more controlled, experimental settings such as laboratories[13]. Throughout the 2000s, a few volumes[15–17] and papers appeared which broadened the range of examples of design research and examined its application to other settings such as learning technologies[9,18,19].

Anderson and Shattuck[4] explain a few defining characteristics of design-based research including being situated in the educational context, focusing on the iterative design of an intervention, connections to design principles, and collaboration between researchers and practitioners. Penuel, Fishman, Cheng and Sabelli[12] frame design research as a method for creating sustainable change in education contexts. A defining feature of design research is documentation of iterative cycles of model design[5,9]. In some reports of design research, the investigators include explanation of the revisions made to their design over time grounding those revisions in both theoretical implications and results of data collection and analysis cycles[9,18,20]. In our case, the model under design is a teaching development group model used to increase the successful implementation of interactive teaching strategies. Our goal with the teaching development model was to create a sustainable model for teaching development. The cycles of design integrate theory about the context (in this case, teaching and learning) and respond to the constraints of the context for implementation.

A second feature of design research in education relevant to our study is the focus on elaborating design principles. Collins, Joseph and Bielaczyc describe two studies that are grounded in design principles for creating learning environments[19]. As stated by Anderson and Shattuck, "Designs evolve from and lead to the development of practical design principles, patterns, and/or grounded theorizing." (p. 17)[4]. This focuses the work on principles that form a sharable model and create a tool that can be adapted and transferred to other contexts. As an example, the six principles for model-eliciting activities[21,22] were created by teachers who wanted to develop thought-revealing activities for students and now the principles are used to guide task design in engineering education settings K-16[22]. So, while an individual model-eliciting activity may be designed for one particular classroom or school, the principles for design are transferable to other settings where tasks are needed. In our case, we began with a few guiding principles that emerged from our review of literature and experience with teaching, and then refined and added principles as the teaching development project proceeded. Additional examples from engineering education focus on designing learning environments or other activities for students[20,23].

Consistent with recommendations for design research to bridge theory and practice, the principles in our project attempt to bridge a gap between research-based practices for teaching and implementation in classrooms by defining a teaching development model for faculty members. Jamieson and Lohmann propose that research projects in education need to create connections between research results and the concerns of instructors in the classroom[24]. Others have pointed to the need for changes in professional development for engineering educators in order to increase the connections between research-based teaching practices and classroom use[25,26]. There are a multitude of practical questions faculty have about incorporating such interactive teaching strategies (e.g., whether to grade or assess student work? what kinds of tasks are useful?). Our professional development model could be characterized as a professional learning community[27]. Borrowing from K-12 models for teacher professional development that emphasize the need for ongoing, sustained professional development opportunities for teachers in order to have impact on practice[28], we adopted a strategy similar to a professional learning community model that is gaining in popularity in other engineering education projects[29,30]. In this type of development, instructors work in a small group during the academic year to have a regular time for discussion of teaching practice. Our project tested and developed design principles for such learning communities for higher education faculty in STEM disciplines. For example, from the start, using small groups that would be sustained over at least one academic year was a critical principle for guiding the work[31,32].

Methodology

Because we have framed the project as a design research study, we are adapting reporting categories based on the recommendations of Collins, Joseph and Bielaczyc: Goals, Settings, Description of Each Phase, Outcomes, and Lessons Learned (p. 38-39)[19].

Goals

The overarching goal of the project was to encourage more interactive teaching methods (e.g., in-class formative assessment, in-class problems) to be used in engineering courses. In order to support instructors in learning about new teaching strategies and then implementing them in their classes, we created teaching development groups guided by a few principles: small groups, sustained interaction and supporting small changes. We have discussed these in more detail elsewhere. From the start of the project, they served to support a structure in which small numbers of faculty could discuss teaching and try new strategies. Part of our objective as a design research project was to continue to examine and refine them over time by responding to practical considerations and the need for a sustainable model[33]. There are a wide range of efforts that serve to increase awareness, but we added the need to use new teaching methods in conjunction with learning about them.

Descriptions of Each Phase

In the first phase, the group leaders formed a teaching development group of their own, and we met in monthly phone conferences to discuss their progress using interactive teaching methods in their own classes. Group leaders were selected because we knew they were interested in interactive teaching strategies and were interested in continuous improvement of their teaching. In the second phase, the group leaders formed a teaching development group of their own for a year before facilitating groups at their own institutions. Four teaching design groups, each composed of 4-7 instructors, met regularly over the course of an academic year. The instructors were primarily from engineering but some groups included other STEM instructors (including graduate students).

Throughout the project, we collected meeting notes for each phone conference with the group leaders. Later in the project, we collected group leader reflections and participant surveys in order to document the design and implementation of the faculty teaching design groups. In this paper, we focus on the group leader reflections and discussion at the final meeting to discuss the design process as observed in the groups. Each group leader wrote a narrative about their group responding to a short set of prompting questions about group composition, challenges of the group, and structuring of the group. These narratives were written during the final meeting and discussed as a group to ensure they reflected each group's story accurately and comprehensively. To explore the design process, we also include the case of one instructor who participated in the groups and who is a co-author on the paper. Craig's case is presented in narrative analysis based on our conversations with over the last few years and a formal, semi-structured interview[34]. The analysis of the data was conducted using organizational coding first followed by theoretical coding to understand the elements of a teaching design process[35].

Results and Outcomes

Design Cycle for Teaching with New Strategies

Consistent with a design process metaphor, the group leaders reported on three distinct phases in their participants' work to try new teaching strategies: planning, implementation, and reflection. These phases emerged as names for the process as experienced by the group leaders and were named as such as substantive categories that reflect the beliefs and understandings of the participants in the project[35]. While design is a more complex process than what is captured by these three overarching phases, the design process often includes at least these three with differences and interpretations that may vary by context[8]. Planning, in our case includes how instructors consider the content, pedagogy, constraints, students' needs, and their objectives for the class. We use it broadly to include both how they plan even before a class begins and smaller cycles of planning within the semester as they make adjustments to teaching. Then, the implementation phase is how the strategies play out in the classroom. These first two stages parallel what Clements refers to as the "intended curriculum" or "planned curriculum" and the "implemented curriculum" [6]. Broadly, these terms refer to what the instructor planned to do in the classroom and intended to have happen. In the next phase, the implemented curriculum is what then actually plays out. Finally, there is a reflection phase in which the instructor considers what happened, how it met the objectives for the teaching strategy, and what needs to be changed for the next implementation. The process of designing teaching then, requires reflective practice to use what was learned or gathered in teaching to then inform future teaching[25,36].

The design cycle, as constructed by the group leaders, seemed to occur on a semester-to-semester (or quarter-to-quarter) basis where one semester was for planning, the next semester was for implementation, and the subsequent semester was for reflection. However, we can also see how these three phases could occur within one semester from class session to class session. For example, cycles of re-design happen when an in-class problem takes longer in class than expected or students have unexpected questions about the material. The instructor must make changes on-the-fly or adapt the next class session. Also, there is overlap between reflecting about the previous semester or class session while planning for the next one.

The Case of Craig

Craig's teaching story is used as a case in this paper about how the design process for teaching evolves over time and how an instructor makes changes over time based on an interaction between needs, concerns, and constraints while going through each phase of the design cycle (planning, implementation, reflection) with the support of a teaching development group. Over the past few years and supported by his colleagues in electrical and computer engineering, he has been slowly making changes in his teaching. A year before the grant began, an informal reading group in the department formed to discuss *How Learning Works*[37]. When we first met Craig and he joined the book discussion group, he was a traditional instructor and relied almost exclusively on lecturing to the students in his classes. He lectured from PowerPoint slides and his main concern in early conversations was "covering the content" and how he could get through the material for students during the lecture. He spent a lot of time preparing his lectures and working to ensure they were clear and comprehensive. Coverage was a strong concern for him, but he also felt pressured for time to "cover" everything he needed to go over for his teaching.

Incorporating In-class Problems Over Multiple Semesters

Then, when the grant project began, he was invited to participate in the small teaching development group that formed in his department. His group consisted of other engineering faculty discussing their teaching. They had varied experience using interactive teaching strategies. Some were new to using formative assessment and some had been using in-class problems for a long time. In our interview, he stated that conversations with other faculty and a friend who taught high school physics “made me aware that simply lecturing to students, while it made me feel good about what I was able to cover and accomplish and the structure I was able to bring, maybe wasn't the right way to go about teaching and I had to step back and consider what the point of teaching was. It wasn't about what I could convey to them so much as what they could learn in the classroom so that's when our conversations started to revolve around what we could do in our classrooms to improve the learning.” At the time, he also learned about an iClicker system that faculty in the sciences were using in their classrooms to ask students questions and get responses immediately in class. The instructors he observed were asking 1-2 questions for feedback during each class. He thought this might be a way to engage the students more in the lectures and help them learn more effectively. Given his concerns for increasing their engagement in class and shifting away from just conveying the content, he began to plan how he would incorporate more in-class exercises in his class sessions.

While still participating in the teaching development group, he began using more problems in class. In the implementation phase, he would lecture for a little bit and then ask a question or two for students to think about what had been taught. Then, he repeated this cycle over and over during the class session. A challenge that emerged was that when the students were finishing the problems at different rates. He was concerned that some students were waiting while the rest of the class was finishing. In addition, he also found himself not finishing his lectures and needing to tell the students to read the rest of the slides on their own. He was beginning to see a conflict between his goal to cover the content and his goal to break up the lectures in order to have more student engagement. To address this, his plan for the upcoming semester is to lecture briefly at the beginning of class (about 15 minutes) and leave the remainder of class for the students to work on problems in small groups or pairs. He described his goal for this technique as follows, “With the previous iteration of the class, I didn’t have an opportunity to go and address individual students because there was limited time and the rest of the students were waiting on those students so I had to move on to the newer material. I’m hoping that by covering everything at once and allowing the students that know or understand the material to move through the exercises on their own, I can now then address the portion of the class that needs help without feeling that I’m slowing everybody else down.” His goal is for the brief lecture to be an overview of the content and students will have access to the longer, more detailed lecture online to review independently.

Considering the Purpose

Throughout the design iterations for his teaching, Craig repeatedly returned to and reconsidered the purpose for teaching and learning in designing the class. This is most evident in two epiphany moments that occurred along his movement from a primarily lecture-driven classroom to a problem-centered classroom described above. His first epiphany moment came when a student in class asked if he could post the slides for class earlier so she would have a chance to review the in-class problems before coming to class. His immediate thought when she asked was to say “no” because the goal was for the problems to be completed in class. However, he had a second thought, “I suddenly stopped and kind of chuckled to myself and said ‘no the actual purpose of the in-class exercises is to help them learn and if they want to learn independently, so much the better’. So, isn't that the point of this? Is to get them involved in their own education? It was at that point that I realized that sometimes you have to stop, and, while you think you have a reason for doing something, you have to think about what the real reason is for doing something. For the iclickers, I wanted the students to be engaged in class, but really the bigger purpose of the questions was to get them to think on their own and to get them actively involved in their education.” In this moment, he had to consider the larger objective for the in-class problems, students' learning. Throughout his design of in-class problems, he continually came back to considering teaching from the perspective of the learners' needs.

In a second epiphany moment, after he had begun using the in-class problems, he came to a point where “…no matter what I tried to do, there's almost conflicting objectives, at least for me there was, it was the idea that to get the students more involved was important, to get them engaged, get them to learn and retain the information required some relinquishing of control of the class. But at the same time, I felt like there was a list of topics that had to be covered and I had to cover everything and I had to cover everything in nth order detail and the ability to do both became a major challenge for me.” The tension at this point was between two objectives: covering information and getting the students involved so they would learn what they needed to know. Eventually, he reached a point where he stated “I finally just realized there was no way I can effectively cover all this material in an hour and fifteen minutes and serve a purpose. Be useful.” He experimented during one class with pushing his slides off to the side (making them available to students for review later) and, as he called it, “adlibbing” from the whiteboard from a few topics. In a related epiphany, he realized he was regularly running out of time to cover all of his lecture material while balancing using the in-class problems so the students were reading the rest of the lecture independently anyway. He realized he could make the out-of-class lecture review part of the design of the class. The testing of an entirely new strategy and realizing the long lectures were no longer purposeful then prompted re-design of the whole class to having short overview lectures followed by in-class problems.

These two epiphany moments shape the design cycle for in-class problems by demonstrating how Craig was incorporating the theories about teaching and learning he was learning from his teaching development group with his experience as an instructor. He planned, implemented, and reflected about his new teaching strategies over time while returning throughout this process to the larger purpose of teaching - students' learning. This focus on purpose motivated modifications he made to his use of the in-class problems and iClicker questions. In addition, he was supported throughout by participation in a teaching development group and colleagues who provided feedback and advice.

Lessons Learned: Principles for Designing Teaching Development Groups

Craig's refining of strategies for increasing student engagement in class was supported by his participation in a teaching development group. We have described aspects of the teaching development groups elsewhere[31,32]. The design principles that were both used to inform the teaching development groups and which emerged as critical characteristics for similar groups were refined over the three years of the project as the group leaders worked with their groups and as they reflected back on the experience in our final meeting where they wrote their narratives. Craig's story is an example of how the principles we used to create the teaching development groups were successful at supporting teaching change over time. The five principles that emerged from our final discussions with the group leaders were: small groups, small changes, structured, self-motivated, and sustainable.

The small groups aspect is consistent with other recommendations for professional development for teaching across K-12 and higher education. In previous work, we discussed how the small groups supported collaboration, feedback, and a developed a sense of community among participants. Then, to offer a sense of structure, we both asked the participants to engage in discussions about outside resources about teaching and learning and asked the participants to try a strategy in their classrooms. In Craig's case, as he learned more about the importance of student engagement in learning, he incorporated that goal into his teaching strategy. Combined with the expectations for participation, group leaders found it was important to schedule meetings for the semester ahead of time to provide a regular time for discussions and accountability for meeting. Also, for small changes, we did not expect large changes to teaching all at once. We provided a space in which small changes could be supported as initial steps and interaction with other instructors who were using more complex forms of student engagement (e.g., reading summaries for a graduate course, longer in-class, small group problem solving). This is consistent with recent recommendations for teaching change over time[36]. The self-motivation principle refers to the need for instructors to participate in a group from their own interest in working on their teaching and seeking out new strategies. For the group members to feel comfortable sharing and for their to be regular participation, the members must be their of their own choice and interest. Also, the changes they make need to be ones of their own choosing in order to increase their interest in making them work. Finally, all of the other principles in concert are designed to create a sustainable structure. Sustainability also comes in the form of each group responding to the current needs at their institution or department and creating a meeting structure that works for them.

Conclusions & Significance

Design-based research in engineering education would seem to be a natural fit and could provide a framework for considering teaching as a design process. This could inform two types of education research endeavors. First, individual instructors engaged in a scholarship of teaching can think about how they design and document learning in their settings. The three design phases identified by our group leaders create a structure for analyzing the interaction between planned goals, objectives, and strategies and the implementation of those strategies. The reflection phase could include instructors examining data from their classrooms in order to develop a scholarship of teaching[25]. In our current project, some members of the group are beginning to engage in more formal data analysis and collection of data from their classrooms to inform their teaching and be able to share results with other STEM faculty. Understanding teaching as a design process also emphasizes that in early stages of attempting new innovations, experimental methods may not be sensible until the relevant variables, characteristics and factors informing the implementation are understood more deeply.

Another arena for considering design-based research is in the incorporation of online tools and other technologies[5,9]. A result of such work can be more than understanding of what worked and for which students, but also creating design principles that can help other instructors successfully implement emerging technologies. Some of the instructors in our groups were using flipped classroom models. The outcome of these projects from a research standpoint can be not only what the students learned, but also an investigation of the design process. What did the instructor try and how did it meet the objectives of the instructor and the course? Why were certain decisions made about the design of the course? For faculty teaching development, a design metaphor emphasizes that teaching is inevitably a work in progress that is always changing and shifting depending on context, new innovations, changing requirements, and other constraints. In addition, faculty who may be new to teaching innovations can consider how to adjust practice within current contexts in a systematic but reasonable fashion.

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